

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY)

2. REPORT TYPE
Technical Papers

3. DATES COVERED (From - To)

4. TITLE AND SUBTITLE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

2302

5e. TASK NUMBER

MIG2

5f. WORK UNIT NUMBER

346120

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

8. PERFORMING ORGANIZATION
REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/PRS
5 Pollux Drive
Edwards AFB CA 93524-7048

10. SPONSOR/MONITOR'S
ACRONYM(S)

11. SPONSOR/MONITOR'S
NUMBER(S)

Please see attached

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

20030128 229

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:

17. LIMITATION
OF ABSTRACT

18. NUMBER
OF PAGES

19a. NAME OF RESPONSIBLE
PERSON

Leilani Richardson

19b. TELEPHONE NUMBER

(include area code)
(661) 275-5015

a. REPORT

Unclassified

b. ABSTRACT

Unclassified

c. THIS PAGE

Unclassified

A

23021180

MEMORANDUM FOR PRS (In-House Publication)

FROM: PROI (STINFO)

23 May 2001

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-2001-123**
Liu, C.T., "Hybrid Experimental-Numerical J-Integral Analysis and Crack Growth Resistance of a
Particulate Composite Material"

International Conf. on Computational Engineering & Science
(Puerto Vallarta, Mexico, 24-28 August 2001) (Deadline: 15 June 2001)

(Statement A)

1. This request has been reviewed by the Foreign Disclosure Office for: a.) appropriateness of distribution statement, b.) military/national critical technology, c.) export controls or distribution restrictions, d.) appropriateness for release to a foreign nation, and e.) technical sensitivity and/or economic sensitivity.

Comments: _____

Signature _____ Date _____

2. This request has been reviewed by the Public Affairs Office for: a.) appropriateness for public release and/or b) possible higher headquarters review.

Comments: _____

Signature _____ Date _____

3. This request has been reviewed by the STINFO for: a.) changes if approved as amended, b.) appropriateness of references, if applicable; and c.) format and completion of meeting clearance form if required

Comments: _____

Signature _____ Date _____

4. This request has been reviewed by PR for: a.) technical accuracy, b.) appropriateness for audience, c.) appropriateness of distribution statement, d.) technical sensitivity and economic sensitivity, e.) military/national critical technology, and f.) data rights and patentability

Comments: _____

APPROVED/APPROVED AS AMENDED/DISAPPROVED

PHILIP A. KESSEL Date
Technical Advisor
Space and Missile Propulsion Division

Hybrid Experimental-Numerical J-Integral Analysis and Crack Growth Resistance of a Particulate Composite Material

C. T. Liu
AFRL/PRSM, 10.E. Saturn Blvd.
Edwards AFB CA 93524-7680

Javier Gonzalez
Graduate Aeronautical Laboratory
California Institute of Technology
Pasadena, CA 91125

Abstract

In this study, a hybrid experimental-numerical method was used to determine the J-integral value in a particulate composite material subjected to a constant strain rate condition. The experimental data were analyzed and the results are discussed.

Introduction

An important engineering problem in structural design is evaluating structural integrity and reliability. It is well known that the strength may be degraded by the presence of cracks in the material. In order to determine the severity of the crack or the ultimate service life of the structure, the failure criterion should include the crack propagation aspect of the localized failure. In order to achieve this goal, the effects of crack sizes and the rate of growth on the fracture resistance of the material need to be investigated.

Crack propagation in particulate composite materials, containing hard particles embedded in rubber matrix, has been an important subject of research for many years (1-4). The basic approach used in characterizing crack growth behavior of these materials is based on linearly elastic or linearly viscoelastic fracture mechanics. Experimental results reveal that a power law relationship exists between the crack growth rate and the Mode I stress intensity factor. This experimental finding supports the linear viscoelastic fracture mechanics theories developed by Knauss (5) and Schapery (6).

In this study, edge-cracked sheet specimens (Fig.1) were used to investigate the crack growth behavior in a particulate composite under a constant strain rate (0.067 min^{-1}) at room temperature. The specimens were made of a highly filled polymeric material, containing hard particles in a rubbery matrix. A 12.7 mm crack was cut at the edge of the specimen with a razor blade. A hybrid method, consisting of experimental and numerical analyses, was used to determine the J-integral as a function of the applied strain. The experimental data were analyzed and the results are discussed.

← In this sentence, you might want to list "Schapery (5)" first, then "Knauss (6)" to keep references in order.

The experiments

In this study, California Institute of Technology's testing equipment was used to conduct the constant strain tests. It includes a straining stage driven by a stepping motor through a flexible cable, a Nikon microscope, a CCD camera, and a personal computer with a frame grabber unit. The straining stage is mounted on a positioning stage, for which a joy-stick controller allows the positioning of the straining stage under the Nikon microscope. A detailed description of the testing equipment can be found in Ref. 7.

Add a space here

During the test, two light sources were used and their positions were chosen carefully to minimize the shadows on the specimen surface. The deformation process was monitored with a 200 mm zoom lens that attached to a CCD camera, which captured an area of 24 mm by 18 mm on the specimen surface. The images of the specimen surface were stored at a rate of one image per five second, and they were used to determine the strain fields near the crack tip.

Data analysis

In this study, digital image correlation techniques, developed by Sutton and his colleagues (8) and improved by Vendroux and Knauss (9), were used to measure the displacement fields and their gradients from images of undeformed and deformed states. These ^{is} information, together with a Ramberg-Osgood constitutive law, ^{was} ~~were~~ used to calculate the strain, stress, energy density, and J-integral values for a given applied strain.

A J-integral computer program was written and incorporated in a finite element computer code (FEAP). The accuracy of the J-integral program was checked by calculating the J-integral for a given HRR field associated with a known J-integral value. The result indicates that the calculated and the prescribed J-integral values differ by 3%. The path-independent nature of the J-integral was checked by computing the J-integral values along 9 different rectangular paths. The closest path to the crack tip was 1.9 mm from the crack tip whereas the farthest one was 5.3 mm from the crack tip. The results indicate that the variation of the computed J-integral values along different paths is within 1%.

In order to check the accuracy of the digital image correlation technique, a specimen of homogeneous silicone rubber without a crack and coated with microscopic speckles was stretched sequentially and uniaxially to a maximum strain of 70% in a sequence of 12 deformation steps of 5.08% strain each. These strains were recorded (optically) with the aid of a microscope by keeping track of the special marks (equal to prescribed strain). In addition, the digital image correlation program was used to compute the strain at a given deformation step. A comparison of the prescribed strain, obtained optically, and the computed strain, obtained by digital image correlation technique, revealed that a maximum deviation of 1% occurs at a strain of 40%. This precision is considered to be acceptable for experimental mechanics investigation.

Results and Discussion

A plot of J-integral values as a function of the applied strain is shown in Fig. 2. It is noted that the rate of change of the J-integral value per unit of the applied strain level increases significantly when the applied strain level is high. Experimental results reveal that the J-integral values vary among the 9 paths, and the variation increases with increasing applied strain. However, the variation is small, especially when the applied strain level is low. A plot of the standard deviation of the J-integral values among the 9 paths as a function of the applied strain is shown in Fig. 3. It is seen that the standard deviation increases with increasing applied strain levels, and at higher applied strain levels the standard deviations fluctuate. It is believed that this phenomenon is due to the microstructure effect and damage developed in the material under higher applied strain levels. Based on these experimental findings, on the first approximation, it can be assumed that the J-integral is independent of path.

— add a space where indicated

The crack growth resistance curve, plotted the J-integral value versus the crack growth increment, is shown in Fig. 4. It is noted that a considerable amount of stable crack growth takes place before the unstable crack growth occurs. The J-integral value corresponding to the unstable crack growth is 3 times higher than that corresponding to the onset of crack growth. A plot of crack growth rate versus J-integral value is shown in Fig. 5. According to Fig. 5, a power law relationship exists between the crack growth rate and the J-integral. Mathematically, it can be represented as

$$da/dt = C J^B$$

where C and B are constants.

Conclusion

In this study, a hybrid experimental-numerical method was used to determine the J-integral value of a particulate composite material. Experimental findings reveal that the local J-integral value along a given path of integration fluctuated due to the nonhomogeneous of the microstructure and the fluctuations along different paths of integrations vary. However, the variations of the accumulated or the final J-integral values among the ten different paths are small. Therefore, on the first approximation, it can be assumed that the J-integral value is independent of the path of integration. In addition, a considerable amount stable crack growth takes place in this material and a power relationship exists between the crack growth rate and the J-integral.

References

- 1/ Liu, C.T., 1990. Crack Growth Behavior in a Composite Propellant with Strain Gradients - Part II, Journal of Spacecraft and Rockets, 27: 647-659.
- 2/ Smith, C.W. and Liu, C. T., 1991. Effects of Near-Tip Behavior of Particulate Composites on Classical Concepts, Journal of Composites Engineering, 1, 4: 249-256.

either use "nonhomogeneous" or "nonhomogeneity"
Please add a space

← "of"

3. Liu, C. T., 1993. "Investigating the Near Tip Behavior and Damage Characteristics in a Particulate Composite Material," ASTM-STP-1189: 668-679.
4. Smith, C. W., Wang, L., Mouille, H., and Liu, C. T., 1993. "Near Tip Behavior of Particulate Composite Material Containing Cracks at Ambient and Elevated Temperatures," ASTM-STP-1189: 775-787.
5. Schapery, R.A., "On a Theory of Crack Growth in Viscoelastic Media, Report MM 2765-73-1, Texas A&M University, March 1973.
6. Knauss, W.G., "Delayed Failure - The Griffith Problem for Linearly Viscoelastic Materials," International Journal of Fracture Mechanics, Vol. 6, March 1970; 7-15
7. Gonzalez, J., "Full Field Study of Strain Distribution Near the Crack Tip in Fracture of Solid Propellant Via Large Deformation Digital Image Correlation and Optical Microscopy," Aeronautical Engineering Thesis, California Institute of Technology, Pasadena, CA 91125, 1997.
8. Sutton, M.A., Cheng, M., Peters, W. H., Chao, Y. J., and McNeill, S.R., "Application of an Optimized Digital Correlation Method to Planar Deformation Analysis," Experimental Mechanics, Vol.4, No.3, PP 143-150, 1986.
9. Vendroux, G. and Knauss, W. G., "Deformation Measurements at the Sub-Micron Size Scale: Refinements in the Algorithm for Digital Image Correlation," GALCIT SM Report 94-5, California Institute Technology, CA 91125.

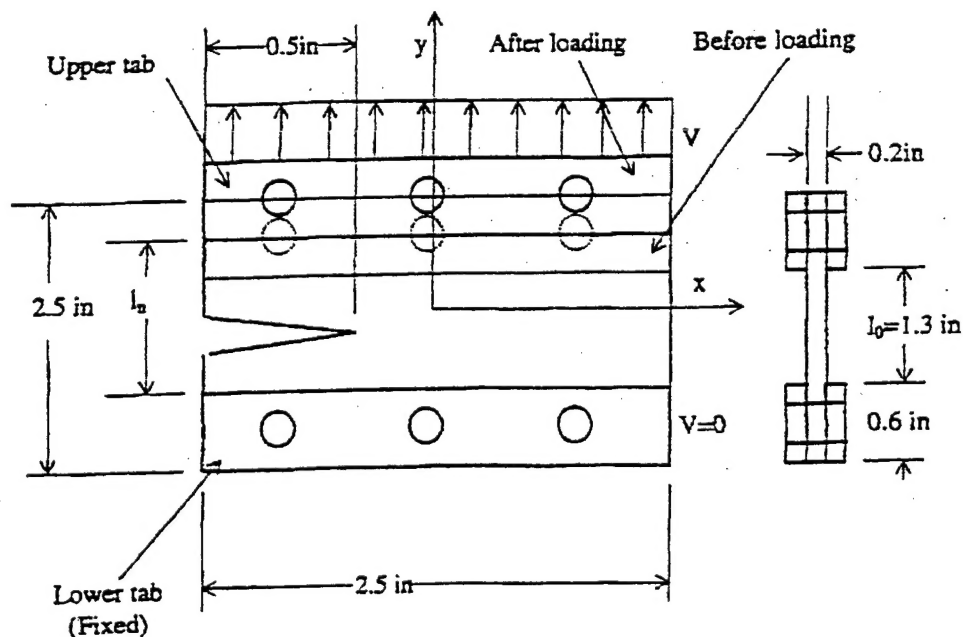


Fig. 1 Specimen geometry.

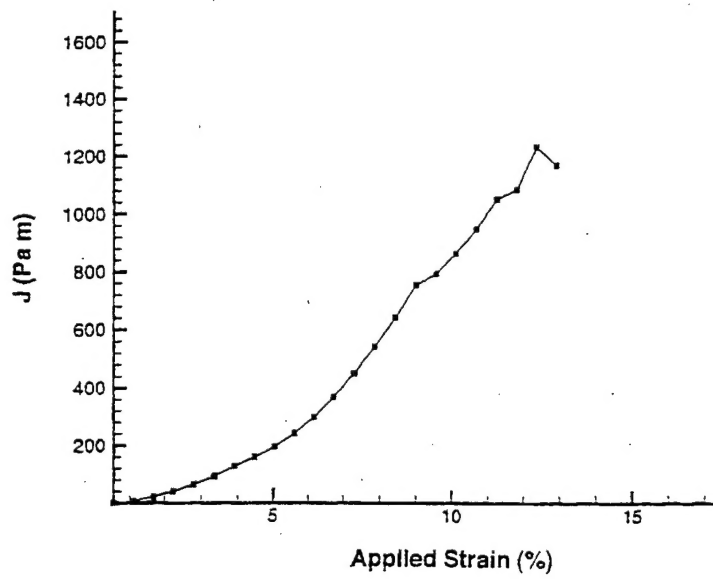


Fig. 2 J-integral versus applied strain.

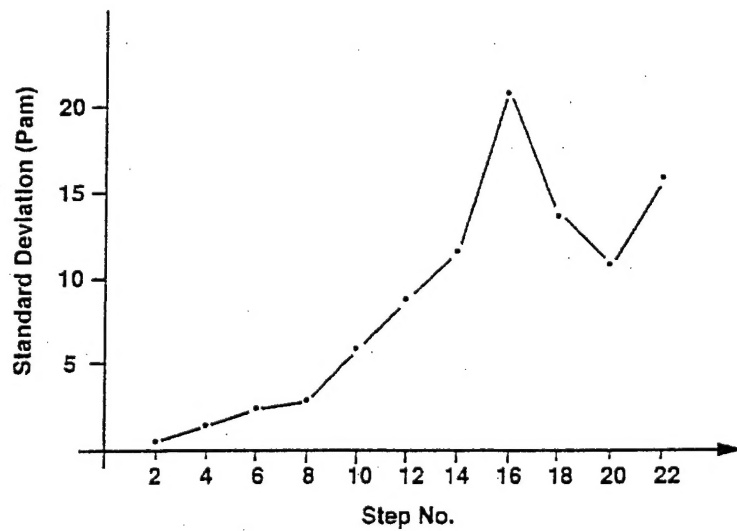


Fig. 3 Standard deviations of J-integral versus step numbers.
(1 step = 0.56% strain)

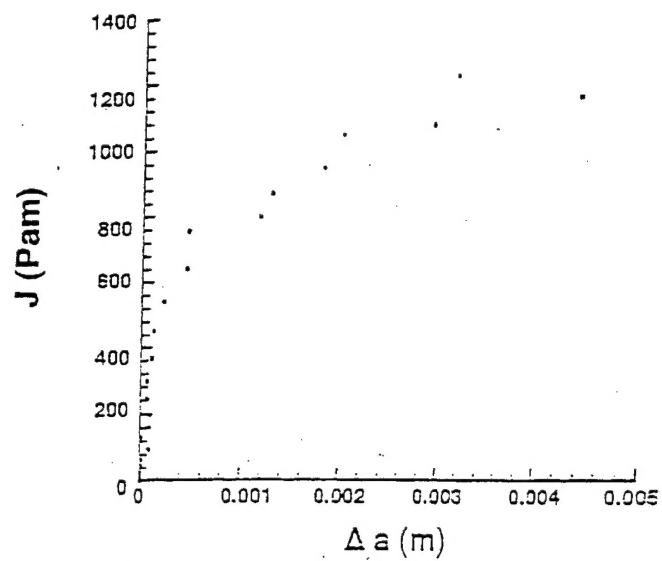


Fig. 4 Crack growth resistance curve.

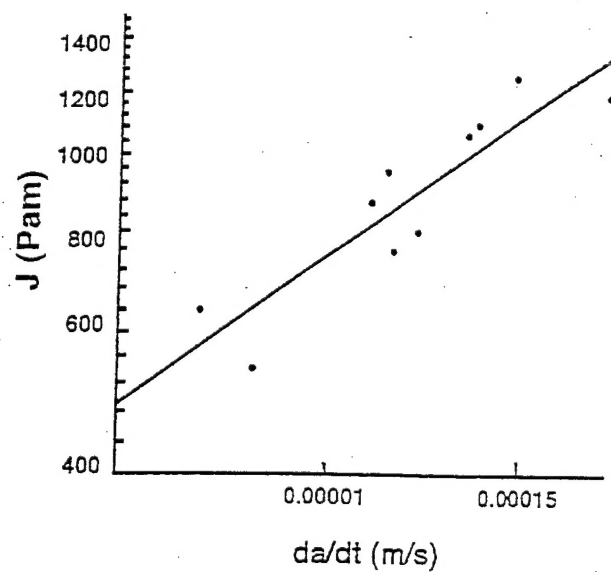


Fig. 5 Crack growth rate versus J-integral.